A simple model for the thermal radiation spectrum of a system with noon-uniform temperature

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Using a simple model, we show that the thermal radiation from a system with non-uniform temperature can exceed the intensity of an isothermal blackbody with the same average temperature. The results might be relevant for recent observations of exceedingly high thermal emission from tungsten photonic crystals. Our results point to the importance of the detailed temperature distribution in the sample for understanding the emission phenomena. We will also model the possible development of hotspots in the experimental system.

Holographic Lithography of Yablonovite-like Photonic Crystals

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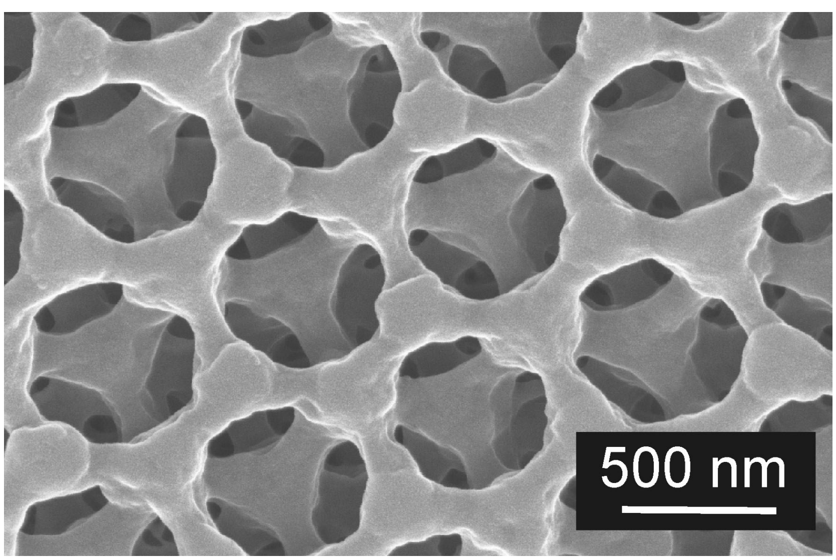
Four-beam holographic lithography [1,2] is a promising technique for fabricating large-scale three-dimensional (3D) Photonic Crystals. Only recently, we [3] and another group [4] have identified parameters for the experimentally preferable "umbrella" geometry leading to a complete 3D photonic band gap (5.8% gap/midgap ratio) after silicon backfilling (same space group as the celebrated Yablonovite structure). Ref. [4] has also shown SEM micrographs but no optical spectra have been published so far. Here, following along the lines of our Ref. [3], we further explore the parameter space using crystallographic space group analysis. We indeed find parameters that lead to a slight increase of the above band gap. Furthermore, we find that this optimum parameter choice is fairly robust in terms of deviations from the ideal. Using beam parameters corresponding to optimized interference contrast [3] and 532-nm exposure wavelength, we have fabricated three-dimensional Photonic Crystal templates (see figure). Optical characterization is in progress.

[1] M. Campbell, D. N. Sharp, M. T. Harrison, R. G. Denning, and A. J. Turberfield, *Nature*, **404**, 53 (2000).
[2] Yu. V. Miklyaev, D. C. Meisel, A. Blanco, G. von Freymann, K. Busch, W. Koch, C. Enkrich, M. Deubel, and M. Wegener, *Appl. Phys. Lett.*, **82**, 1284 (2003).
[3] D. C. Meisel, M. Wegener, and K. Busch, *Phys. Rev. B*, **70**, 165104 (2004).
[4] C. K. Ullal, M. Maldovan, E. L. Thomas, G. Chen, Y.-J. Han, and S. Yang, *Appl. Phys. Lett.*, **84**, 5434 (2004).



Infiltration and Inversion of Holographically-Defined Polymer Photonic Crystal Templates using Atomic Layer Deposition

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Holographic lithography[1] is a promising fabrication method for 3D photonic crystals. The technique yields sub-micrometre periodic microstructures in polymeric photoresists with low refractive index contrast. Methods for formation of negative replicas of these templates must be compatible with the low decomposition temperature of the resist. Atomic layer deposition of titania (at $< 100^\circ$ C) has been used successfully in the formation of inverse opals [2]. Here we report the realization of 3D photonic crystals by infiltration and subsequent burnout of holographically-defined polymeric templates. We present reflection and transmission spectra for titania/epoxy and titania/air photonic crystals and correlate them with calculated photonic bandstructures. These results demonstrate the effective combination of two powerful techniques to yield unprecedented structural control at the nanoscale in high index 3D photonic crystals.

[1] M. Campbell et al., *Nature* 404, 53 (2000)
[2] J. S. King, et al., *Adv. Mat.*,*in press*.

Direct Laser Writing of Three-Dimensional Photonic Crystals in High Index of Refraction Chalcogenide Glasses

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We present a two-step method for the direct fabrication of high index of refraction three-dimensional Photonic Crystals.

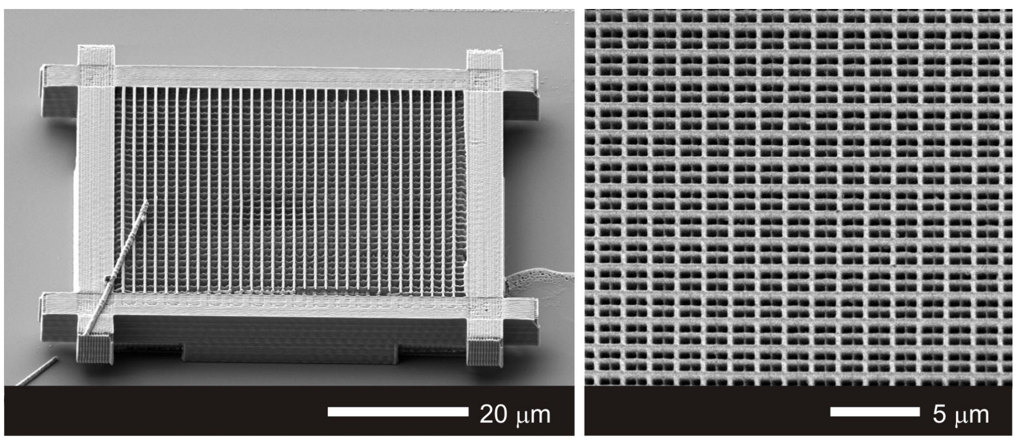

Fig. 1. SEM micrographs of a direct laser written As_2S_3 woodpile. On the left hand side the extremely high selectivity of our specially formulated wet etchant is clearly visible while the overall high definition of the structure can be seen on the right hand side. The rod spacing of this woodpile is 1.5 microns.

Direct laser writing [1] in arsenic-sulphur based thin films of chalcogenide glasses with intense 120fs pulses induces a local chemical phase change via two-photon absorption to As_2S_3. The inscribed three-dimensional Photonic Crystals are subsequently etched out with a specially formulated wet chemical etchant. The index of refraction of As_2S_3 (n = 2.45) is sufficiently high to open a complete band gap in diamond-like crystal structures, e.g., the woodpile structure, although further optimization of the writing process is required to achieve this goal. As our approach does not require any subsequent inversion with high index materials, it might provide a new route for the direct fabrication of functional Photonic Crystals.

[1] M. Deubel et al., *Nature Materials*, **3**, 444 (2004).

New process technique for photonic crystals using gas cluster ion beam

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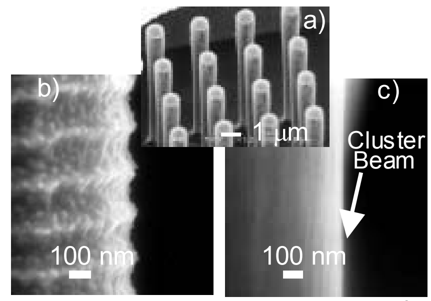

Fig. 1: Photonic crystal structures before (a and b) and after GCIB irradiation (c)

We present a new technique to fabricate high quality photonic crystals. In this technique, gas cluster ion beam (GCIB) is used to reduce dramatically surface roughness of photonic crystal structures. Sidewall surfaces as well as top/bottom surfaces can be smoothed by irradiating chemically reactive gas clusters nearly parallel to the sidewall surfaces, in a similar way of the parallel movement of slurries along the surface in chemical mechanical polishing [1]. We demonstrate a surface roughness at a 0.1 nm level (Fig. 1) that is drastically lower than the sidewall roughness of photonic crystals etched by conventional methods. The advantages of our technique are that GCIB polishes selectively the protruding silicon atoms, and leaves no damage on the surfaces. (This work is supported by NEDO of Japan)

[1] E. Bourelle, A. Suzuki, A. Sato, T. Seki, and J. Matsuo, *Jpn. J. Appl. Phys.*, 43, L1253 (2004).

Deep Submicron Two Dimensional Photonic Crystal Fabrication

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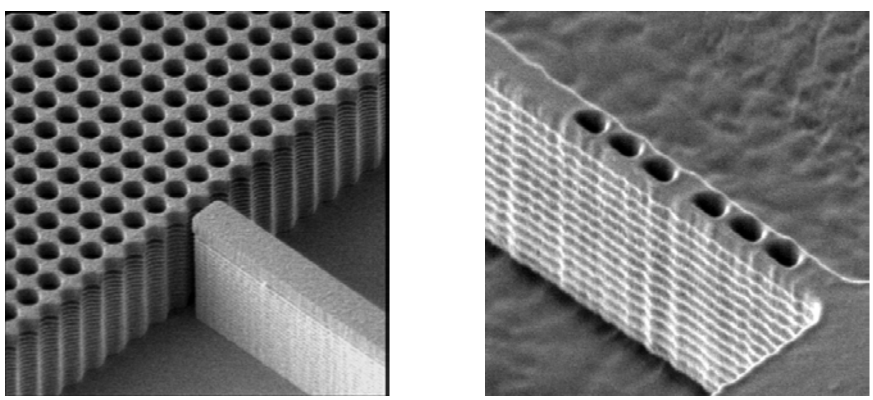
We report the fabrication of deep submicron size two dimensional (2D) photonic crystal (PhC) using synthesized processing techniques of deep UV lithography, time-multiplexed reactive ion etching (TMRIE) and focus ion beam etching.

In this study, 200mm silicon on insulator wafers were used to create mixed density of holes and waveguide pattern needed to form 2D PhC structures. Through use of a KrF based scanner, large array patterns of PhC hole-lattice was transferred together with fine lines of waveguides. In the pattern transfer step following hard mask definition, ultra wide grooves were patterned, aligned to the deep submicron size devices. Following deep etching of more than 50 um by TMRIE, PhC structures are then revealed for device etching. Such design of fabrication process method allows realization of disparate pattern dimensions and also etching depths. Through avoidance of etch loading effect in etching, notching of devices at interface of device silicon and buried oxide layer was avoided. At the same time, a wide process window of lithography for high repeatability patterning was made possible by introduction of singular focused ion beam (FIB) etch used to obtained individual holes on narrow monorail structures in the final step of the process following buried oxide release. The structures of dense holes are shown in Fig. 1a while the released monorail device (with FIB etched PhC holes) is shown in Fig. 1b.



(a) (b)

Figure 1 (a) Structure of dense hole together with fine waveguide; (b) Released monorail structure with FIB etched PhC holes.

Coupled periodic waveguides: From basic idea to efficient photonics components

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An efficient light guiding by several periodic chains of dielectric nanopillars is possible [1]. Periodicity in the guiding direction and coupling between the individual chains lead to strong frequency dispersion of such coupled periodic waveguide (CPW). In this contribution, we study dispersion and transmission properties of CPWs with the aim to design effective and compact photonics components. Bends, directional couplers (Fig. 1) and filters are proposed and numerically characterized by 2D and 3D plane wave expansion and finite difference time domain methods.

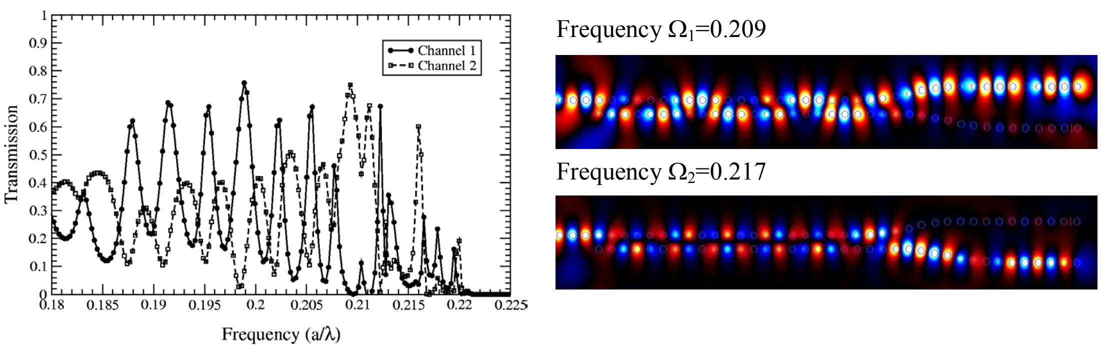

Figure 1. Transmission efficiency (left) and field distribution (right) of a CPW directional coupler.

[1] D. N. Chigrin, et al., *Opt. Express* **12**, 617 (2004)

Left Handed Electromagnetism at Terahertz Frequencies

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We report on the possibility to experimentally demonstrate the left-handed character of metamaterial-based microstructures aimed at operating at Terahertz frequencies. To this aim, left handed transmission lines periodically loaded by shunt inductances and series capacitances along with SRR's and wire arrays on a short scale have been fabricated and characterized in the frequency and time domains. For the latter, with the prospect to reach 1 THz, electro-optic sampling techniques have been specifically developed for vectorial measurements using Franz-Keldysh detection scheme and Low temperature AlGaAs technologies. Direct evidence of lefhandedness is carried out via phase offset analysis compared to band structure calculations. Potential applications in the far infra red region are briefly reviewed.